1. **INTRODUCTION**

A significant ice storm affected the eastern United States on 11-12 December 2008. Ice accumulations of 0.1 to 0.25 inches were observed from the mountains of southwestern Pennsylvania and extended northeastward into New York State and New England. Damaging ice accumulations were observed in New York and New England were ice accumulations ranged from 0.25 to 1.00 inches of ice.

This ice storm was likely one of the more significant and damaging ice storms in the eastern United States since the devastating ice storm of January 1998. This event occurred nearly a year after the Midwestern ice storm of 8-10 December 2007 which produced significant ice accumulations from Oklahoma northeastward to Illinois.

Reports indicated that multiple regions of New York State had hundreds of thousands of customers without power and heat due to downed transmission lines. Estimates and news accounts suggested that over 1 million customers across the northeastern United States lost power due to the storm. In the hardest hit areas of east-central New York, western Massachusetts, Vermont, Connecticut, and western New Hampshire averaged 0.50 to 1.00 inches of ice accumulations. The main cause of the damage was due to ice laden wires and trees falling on wires.

In addition to the loss of power, the ice caused traffic accidents, school closings, and led to at least 4 fatalities.

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1 Wiki site for summary information

Ice storms are well documented across the United States. This event occurred in close proximity to the region of maximum freezing rain activity in the eastern United States of maximum freezing rain (Fig.1: Robbins and Cortinas 2002). The area of maximum activity, 20-30 hours per year, extends from northern Pennsylvania across New York State and into New England.

Cortinas et al 2004 provides a thorough review of freezing rain and ice pellets climatological studies from the published literature. They present the climatology showing New England as the most active freezing rain and ice pellet region in the United States. The maximum time of these events is form November to March. The majority of the events were of relatively short in duration (Robbins and Cortinas 2002) lasting on the order of hours. The event of 11-12 December 2008 fell in this general area. The lighter freezing rain in western Pennsylvania fell in the other area of maximum freezing rain as described by Robbins and Cortinas (2002).

Rauber et al (2001) examined the Valentines Day ice storm of 14-15 February 1990, which affected the Midwest and the study focused on the ice damage in Illinois. Their study showed the importance of maintaining the low-level cold air to maintain ice and mixed precipitation. The key features included a strong surface anticyclone to the north with a quasi-stationary east-west frontal boundary. Though not specifically shown, the pattern indicated a strong upper level ridge to the southeast. The pattern and anomalies with this case were reconstructed using the NCEP/NCAR global re-analysis data and is shown in Figure 1. These data show the key features often associated with significant ice storms.
Other famous ice storms in the literature include the January 1951 southern ice storm (Harlin 19520, the 26-27 December 1969 event (Ackley et al 1970); the March 1960 northern Alabama ice storm (Baker 1960), and the January 1998 Northern New England and Canadian ice storm of 5-9 January (Gyakum and Roebber 2001). Figure 2 shows the large scale conditions associated with the January 1998 ice storm.

Hart and Grumm (2001) showed (their Table 2) the anomalies associated with the January 1998 ice storm made it a top 10 event in terms of total departures from normal in the period from 1949-2000 over the eastern United States. It ranked as the 5th most anomalous event in the eastern United States. This devastating ice storm produced over $3 billion dollars of damage in Canada alone. More than 4 million customers lost power due to damaging ice accumulations in the United States and Canada. This storm is the benchmark storm for severe ice and ice damage in eastern North America.

Critical to identifying potential significant events is the ability to put the pattern into a context. The climate anomalies approach, outlined by Hart and Grumm (2001) and Grumm and Hart (2001) facilitates identifying patterns associated with significant events.
The use of anomalies in the forecast products requires applying these anomalies to model and ensemble forecasts.

In addition to identifying the pattern, forecasts of critical variables associated with ice storms must be examined. Ensemble forecasts of 2m temperatures, probabilities of value above and below 0°C and the probabilities of precipitation type could aid in forecasting these events. Ensembles provide the requisite fields which can display to facilitate probabilistic forecasts.

This paper will document the ice storm of 11-12 December 2007. The goals include putting this event into a meteorological context relative to previously documented ice storms and to show the value of ensembles in forecasting potentially devastating ice storms.

Data for this study include re-analysis climatological data from the NCEP/NCAR global re-analysis project (GR: Kalnay et al 1996). These data were used to reconstruct the patterns associated with previously documented ice storms. The means and standard deviations were used to compute standardized anomalies, displayed in standard deviations from normal (SDs).

Forecasts from the NCEP NAM, GFS, and SREF are represented. The focus will be on SREF products related to forecasting ice storms. Individual models may be of value, but in high uncertainty situations, ensembles are better suited to deal with uncertainty and provide probabilistic products that a single model cannot provide.

Focus is on forecasts products is from 9-11 December 2008. The climatological data used
to compute anomalies was restricted to those produced by the NCEP/NCAR GR data set (Hart and Grumm 2001). They will be presented in relation to model and EPS output.

All data was displayed using GrADS. Anomalies were computed as described Hart and Grumm (2001) and Grumm and Hart (2001). Shaded values show the standardized anomalies computed as:

$$SD = (F - M)/\sigma$$

Where \(F\) is the value from the reanalysis data at each grid point, \(M\) is the mean for the specified date and time at each grid point, and \(\sigma\) is the value of 1 standard deviation at each grid point.

The GEFS, NAM, and SREF forecasts were obtained from NCEP. Plume and precipitation diagrams were produced from the deterministic model runs and the SREF using GrADS.

For brevity not all forecast systems data or all levels and parameters are show. Furthermore, all times will be referred to as 11/0000 UTC for 11 December 2008. Other years and dates when used will be spelled out in order to distinguish them from the event of 11-12 December 2008.

Plume diagrams were computed and produced in real-time. These diagrams are available in real-time and the NWS-PSU website and at the Storm Prediction Center. The plumes show the precipitation by type and over the forecast period for an individual site.

The plume diagram adds value to uncertainty of type, intensity, and timing of periods of precipitation. They also facilitate the evaluation of extreme member’s visual display the probability distribution function.

Figure 3. Total liquid equivalent precipitation (mm) from 0000 UTC 11 through 0000 UTC 13 December 2008. Data from the Stage-IV rainfall dataset.

3. Overview

i. Precipitation estimates

Figure 3 shows the overall estimated liquid equivalent precipitation observed from 11/0000 through 13/0000 UTC. Most of the rainfall over 75 mm fell in the warm air over New Jersey, Long Island, Connecticut and Massachusetts. A large portion of the damaging ice received in excess of 50 mm of precipitation. The hard hit area of western Massachusetts and northwestern Connecticut where 25 mm (1 inch) of ice was reported (NWS Public Information Statements) actually received in excess of 75 mm of liquid equivalent precipitation.

The 6-hourly data revealed that the precipitation began between 11/0600 and 11/1200 UTC (Fig. 4) and spread northward in time. The heavy rainfall along the coast and in New England was observed after 12/0000 UTC (Figs. 5c & 5d) and ended shortly after 12/1800 UTC. A weak
Figure 4. As in Figure 3 except showing the 6-hour precipitation for the periods ending at a) 1200 UTC and b) 1800 UTC 11 December 2008 and c) 0000 UTC and d) 0600 UTC 12 December 2008.

A deformation snow band developed in the cold air and contributed to the liquid equivalent totals as indicated by the narrow band of 2-8 mm of QPF ending at 12/1200 UTC (Fig. 5b). About 1 inch of snow fell in State College, PA with higher amounts closer to the New York border where Coudersport had 8 inches of snowfall.

i. The pattern

Figure 6 shows the pattern over the United States at 11/1200 UTC. The deep 500 hPa low over Louisiana and the accompanying surface cyclone dominate the image. The cold air at 850 hPa (Fig. 6c) and the deep cyclone produced a rare snowfall in the Gulf States with reports of measurable snowfall in the New Orleans area. The strong u-anomalies north of the cyclone were in an area known for snowfall potential (Stuart and Grumm 2006).

By 11/1800 UTC the pattern showed the strong frontal zone over the northwestern United States (Fig. 7c) with the 0C isotherm cutting across northern Pennsylvania into New England. A strong surface high was located in eastern Canada. Though not shown, the surface and 2m 0C contour was 50 to 100 km south of the 850 hPa 0C contour. Fields shown were predicated on the case images shown in Figures 1 & 2.

By 12/0000 UTC (Fig. 8) the low had moved to the Carolina’s. More importantly, the 0C isotherm and the strong baroclinic zone remained in place along the East Coast (not shown) and the low-level easterly jet intensified covering a larger area. Figure 8d shows the surge of +2SD above normal PW values along the coast and the 925 hPa v-winds (Fig. 8a), which were 3 to 4 SDs above normal. These two parameters are good indicators of heavy rainfall.
The 925 hPa winds also showed the strong low-level jet (Fig. 8b) and on the cold side of the baroclinic zone. The frontal trough extending out of the surface cyclone was over the coastal plain. They heavy precipitation ending at this time was north of the surface cyclone (Fig. 4c) and heavy precipitation was about to affect the coastal plain (Fig. 4d).

Figure 9 shows the conditions at 12/0600 UTC. The surface cyclone was over North Carolina with an incipient low over Delaware Bay (Fig. c). The PW anomalies were over +5SDs above normal along coastal New Jersey (Fig. 9d) and a strong southerly jet was focused in this region. This lined up well the 6-hour 25-50mm rainfall rates in Figure 4d. In the cold air, a strong low-level northeasterly jet was present (Fig. 9b). The 0°C isotherm at 850 hPa had moved slightly northward, extending from southern Maine, across central New Hampshire and Vermont to central Pennsylvania, well north of the low-level cold northeasterly jet at 925 hPa. This warm air over cold air set up ideal conditions for freezing rain at the surface.

By 12/1200 UTC, the surface low had developed over Long Island (Fig 10d) and the 0°C isotherm at 850 hPa over New England was still close to the 12/0600 UTC position. Farther west the cold air had move in, turning an residual precipitation to snow fall.

4. FORECASTS

This was the third event in less than 3 weeks where early forecasts from the GEFS indicated a precipitation type issue over the northeast and Mid-Atlantic region. The storm of 30 November 2008, which was mainly a freezing rain and rain
over Pennsylvania, was forecast to be a significant snow storm from forecasts initialized on 26 and 27 November 2008. The Altoona plumes from 03/0000 through 06/0000 UTC are shown in Figure 11. These data show that the GEFS forecast a precipitation event on or about 11 December 2008. The timing was an issue from forecasts initialized at 03/0000 UTC as well as the precipitation type though rain was the dominant precipitation type. The timing of the precipitation improved as the forecast range decreased and the event was focused on the 11th and ending on the 12th. Altoona remained warm enough such that rain was observed, about 40 miles to the north freezing rain was observed in State College where ice accumulations were 0.1 to 0.2 inches. Just 2-5 miles west of Altoona, the mountains had 0.2 to 0.30 inches of ice².

The precipitation type issue did not get any easier farther north in places like Albany, New York where heavy ice accumulations were observed. Plumes from 09/0900 through 10/2100 UTC showed the forecast issues. Initially rain was the dominant precipitation type. Forecasts from 09/2100 UTC showed a mixed event but as the forecast range decreased, freezing rain became the dominant precipitation type.

² Personal observation 12 December 2008.
type as indicated by the forecasts from 10/2100 UTC. Note over 1.27 inches of the QPF was to be rain.

Despite these early GEFS and SREF forecasts showing timing and precipitation type issues, many human forecasts (not shown) indicated a high potential for snow over portions of Pennsylvania into New York. Snow forecasts of 8-10 inches of snow were indicated for portions of Pennsylvania issued as early as 2 day prior to the event (Fig. 14). The plumes implied that snow would not be the primary threat.

The planview SREF PTYPE images are shown in Figure 14. These data are from the 10/0900 UTC cycle. The first image shows the high probability of snow as it emerged at 12/0300 UTC (upper right panel). The probability of freezing rain (lower right) was higher and extended across Pennsylvania into Massachusetts. The freezing rain probabilities were in the 60-80% change. By 12/1200 UTC the probability of snow on the northwest side of the storm increased to over 90% with a broad area of 40-80% probabilities of snow. Reports from New York suggest there was a narrow 7-10 inch snow band over this general area. Note the high probability of heavy rainfall moved to the northeast by 12/1200 UTC and was focused over New England, primarily over New Hampshire and Maine.

Figures 15-17 show that the SREF did a credible job with the placement of the 0C isotherm at 850 hPa and the total QPF and high probability of 1 inch or more QPF when compared to the verifying images. The verifying time of Figure 17 is 12/1200 UTC. Though more precipitation fell over New England after this time, the selected time was representative for the Mid-Atlantic region and southern New England. The pattern of the precipitation shield and the location of the heaviest rainfall aligns well with Figure 1.

5. CONCLUSIONS

A significant ice storm affected the eastern United States from 11 to 12 December 2008. Though freezing rain and accumulating ice was observed from Pennsylvania to Maine, warmer temperatures precluded heavy ice accretion over most of Pennsylvania. Temperatures in Pennsylvania were mainly in the 30-33F range and ice accumulations over 0.20 inches were generally limited to locations over 2000 ft. However, from northeastern Pennsylvania into New England, colder temperatures; many locations remained in the upper 20s; facilitated larger ice accumulations and thus damaging ice was observed over these areas. Thus, from New York to Maine, significant ice accumulations produced widespread power outages affecting over 1 million customers.

The event was relatively well forecast by the NCEP models and ensemble prediction systems which generally showed considerable uncertainty with the timing and precipitation type. They did show a small area of heavy snow along the western edge of the precipitation shield which increased in probability after about 12/0300 UTC. Heavy snow was limited to a few locations in extreme northern Pennsylvania and a stripe across New York and Vermont on the western edge of the larger precipitation shield.

An examination of SREF planview precipitation type images, such as those shown in Figure 14, from 09/0300 through 10/1500 UTC seemed to indicate ice as the higher probability precipitation type until about 12/0300 UTC when probability of snow along the northern and western edge of the precipitation shield rapidly increased. Experiences with SREF and GEFS plumes and PTYPE forecasts typically suggest limited snowfall in areas of mixed precipitation. Over Pennsylvania and eastern New York mixed precipitation types dominated and freezing rain was the key forecast issue in terms of impact.

This was clearly a difficult forecast and they were marginal conditions in the transition zone from ice to snow. It is unclear why early human based forecasts tended toward such high snow accumulations when ensemble precipitation type forecasts indicated a higher probability of mixed precipitation and a significant swath of freezing rain as the dominant precipitation type.
The pattern associate with this event was somewhat similar to the pattern associated with previous large or significant ice storms. A comparison of previous storms from the published literature was presented. These data showed the key signals associated with ice storms which included:

- A strong surface anticyclone to the north with above normal mean-sea level pressure anomalies. In this case a modest 1SD anticyclone moved over Quebec to provide the initial low-level cold air.
- A strong quasi-east west frontal boundary with -1 to -3 SD below normal cold air to the north and normal to above normal anomalies to the south. In this case the 850 hPa temperatures were not significantly below normal in the ice storm region.
- Above normal PW water values over or just south of the affected region.
- An upper level ridge with about 1SD above normal heights at 500 hPa over or east of the affected region.
- A strong easterly jet with -1 to -3 SD anomalies in the cold air at 925 to 850 hPa.
- A strong 850 hPa jet with +1 to +3 SD anomalies in the v-wind component.
- A strong jet with positive u wind anomalies north and east of the affected area.

The event of 11-12 December 2008 appeared to share many of the common characteristics of previously documented ice storms. For example, the antecedent conditions were relatively warm. The day before the event high temperatures in the 50s and 60s were common from Pennsylvania southward into Virginia and fell to near or below freezing rapidly behind a cold front that arrived about 12-18 hours prior to the precipitation.

The anticyclone to the north was well north and a northern stream wave produce low pressure to the northwest. This likely injected the cold air toward the end of the event and may have played a role in the snow band that developed early on 12 December 2008.

6. Acknowledgement

7. REFERENCES


Irland L. C., 2000: Ice storm 1998 and the forests of the Northeast. J. For., 96, 32–40. Find this article online
Figure 7. As in Figure 1 except NAM 00-hour analysis valid at 1800 UTC 11 December 2008. Image is focused over the eastern United States.


Figure 8. As in Figure 7 except showing NAM 00-hour forecasts valid at 000 UTC 12 December 2008 of a) 925 hPa winds and v-wind anomalies, b) 925 hPa winds and u-wind anomalies, c) MSLP, and d) precipitable water.
Figure 9. As in Figure 8 except valid at 0600 UTC 12 December 2008.
Figure 10. As in Figure 6 except valid at 1200 UTC 12 December 2008.
Figure 11. GEFS plumes for a point near Altoona, PA for the forecast cycles at 0000 UTC (upper left) 03 December, (lower left) 4 December, (upper right) 5 December and (lower right) 6 December 2008. Colored lines show the accumulated precipitation by type and match the colors to the left of each image which show the mean, max, and minum values by type along with the total precipitation. The light gray lines show the 6-hour instantaneous precipitation by member.
Figure 12. As in Figure 11 except SREF plumes for a point near Albany, NY initialized at (upper left) 0900 UTC 9 December, (upper right) 2100 UTC 09 December, (lower left) 0900 UTC 10 December and (lower right) 2100 UTC 10 December 2008.
Figure 13. Snowfall forecast for the event showing the day 1 and 2 total snowfall (inches). Image was a forecast from early on 10 December 2008.
Figure 14. Planview SREF precipitation type forecasts from the SREF initialized at 0900 UTC 10 December valid at (upper 4 panel) 0300 UTC 12 December and (lower 4 panel) 1200 UTC 12 December 2008. In each 4 panel image, the 3-hourly precipitation (inches) is shown by the contours. The probability of rain is the upper left image, probability of snow is the upper right image, probability of ice pellets is the lower left image and the probability of freezing rain is in the lower right image.
Figure 15. SREF forecasts initialized at 0300 UTC 10 December 2008 showing in 2 panels (left) 850 hPa temperatures valid at 0000 UTC 12 December 2008 upper panels show the -16,-8, 0 and -16 contour and the spread about the mean. Lower panel shows the mean and the departure of this field in standard deviations from normal. (middle) shows the SREF 850 hPa winds valid at 0000 UTC 12 December. Upper panels shows the u-wind anomalies and the lower panel shows the v-wind anomalies. (right) upper panel shows the probability of 1 inch or more QPF in 24 hours ending at 1200 UTC 12 December. Lower panels show the mean QPF and each members 1.0 contour for the period ending at 1200 UTC 12 December 2008.
Figure 16. As in Figure 15 except SREF forecasts initialized at 0000 UTC 10 December 2008.

Figure 17. SREF forecasts showing of QPF over 1.0 inches for the 24 hours ending at 1200 UTC 12 December 2008 from forecasts initialized at (left) 1500 UTC 10 December, (center) 0300 UTC 11 December, and (right) 0900 UTC 12 December 2008. The upper panels show the probability (%) of 1 inch or more QPF in 36 hours and the lower panels show the ensemble mean QPF (shaded) and each members 1 inch contour.